



# **1<sup>st</sup> generation Laser-Produced Plasma 100W source system for HVM EUV lithography**

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## **Acknowledgments**

**This work was partly supported by the New Energy and Industrial  
Technology Development Organization -NEDO- Japan.**



# Outline

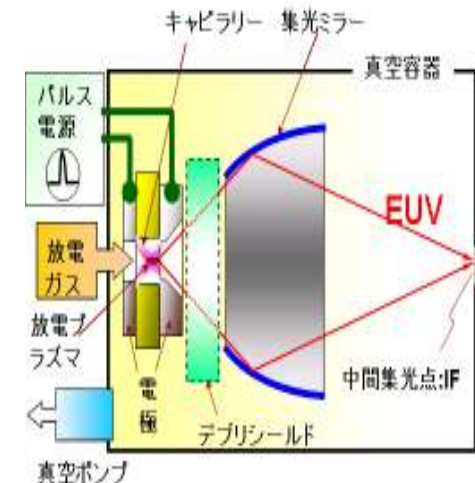
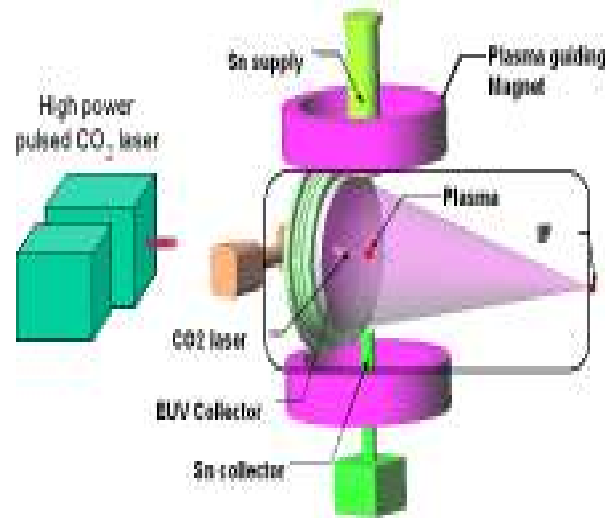
- **Introduction**
  - Concept of Gigaphoton LPP source
- **1<sup>st</sup> Generation system data**
  - Latest data
  - Critical issue and experimental data
- **2<sup>nd</sup> generation system development**
  - Design
  - Status of construction
- **Roadmap update and New facility**
- **Summary**

# EUV sources

## Original technologies

### LPP: CO<sub>2</sub> laser and Sn source


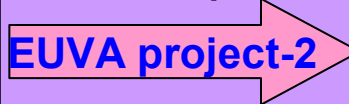

- ① High power pulsed CO<sub>2</sub> laser
- ② Magnetic field plasma mitigation
- ③ Pre-Pulse plasma technology



Type	LPP		DPP
Maker	Gigaphoton	Company A	Company B
Size	Large	Very Large	Small
Power (at present)	104W/21W	90W/20W	34W/34W
Plasma	No electrode	No electrode	Disc electrode
Mitigation	Pre pulse + Magnet	Gas	Gas + mechanical shutter
Life limitation	( several 1000 hr )	Several 10 hr	Several 10 hr
Bottle neck	-	Mirror	Electrode/Mirror
Remark	<ul style="list-style-type: none"> <li>• Theoretically no limit</li> <li>• Engineering items are lot</li> </ul>	• Trade off of power and lifetime	<ul style="list-style-type: none"> <li>• Trade off of power and lifetime</li> <li>• Trade off of power and beam quality</li> </ul>

# EUVA Project (LPP)



	1st Mid term 2004/9	2nd Mid term 2006/3	EUVA -1 final 2008/3	EUVA-2 final ~ 2011/3	<i>Gigaphoton</i>  2011/4 ~
<b>EUV Power (IF)</b> <b>Stability</b> <b>Laser</b> <b>Laser freq.</b> <b>CE (source)</b> <b>Target</b>	<b>5.7W <sup>1)</sup></b> --- <b>YAG:1.5kW</b> <b>10kHz</b> <b>0.9%</b> <b>Xe-Jet</b>	<b>10W <sup>1)</sup></b> $\sigma < \pm 10\%$ <b>CO<sub>2</sub>:2.6kW</b> <b>100kHz</b> <b>0.9%</b> <b>SnO<sub>2</sub> choroid liquid jet</b>	<b>50W <sup>2)</sup></b> $\sigma < \pm 5\%$ <b>CO<sub>2</sub>: 7.5kW</b> <b>100kHz</b> <b>2.5%</b> <b>Sn-Droplet</b>	<b>1st Generation (ETS)</b> <b>110W <sup>2)</sup> /140W <sup>3)</sup></b> $3\sigma < \pm 0.3\%$ <b>CO<sub>2</sub>: 10kW</b> <b>100kHz</b> <b>4%</b> <b>Sn-Droplet</b>	<b>2nd Generation (proto/GL200E)</b> <b>250W (clean@IF)</b> $3\sigma < \pm 0.3\%$ <b>CO<sub>2</sub>: 23kW</b> <b>100kHz</b> <b>5%</b> <b>Sn-Droplet</b>
					

Note)

Primary source to IF EUV transfer efficiency:

- 1) 43%
- 2) 28% with SPF
- 3) 36% without SPF

SPF: Spectral Purity Filter IF: Intermediate Focus



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# 1<sup>st</sup> generation system (ETS device)

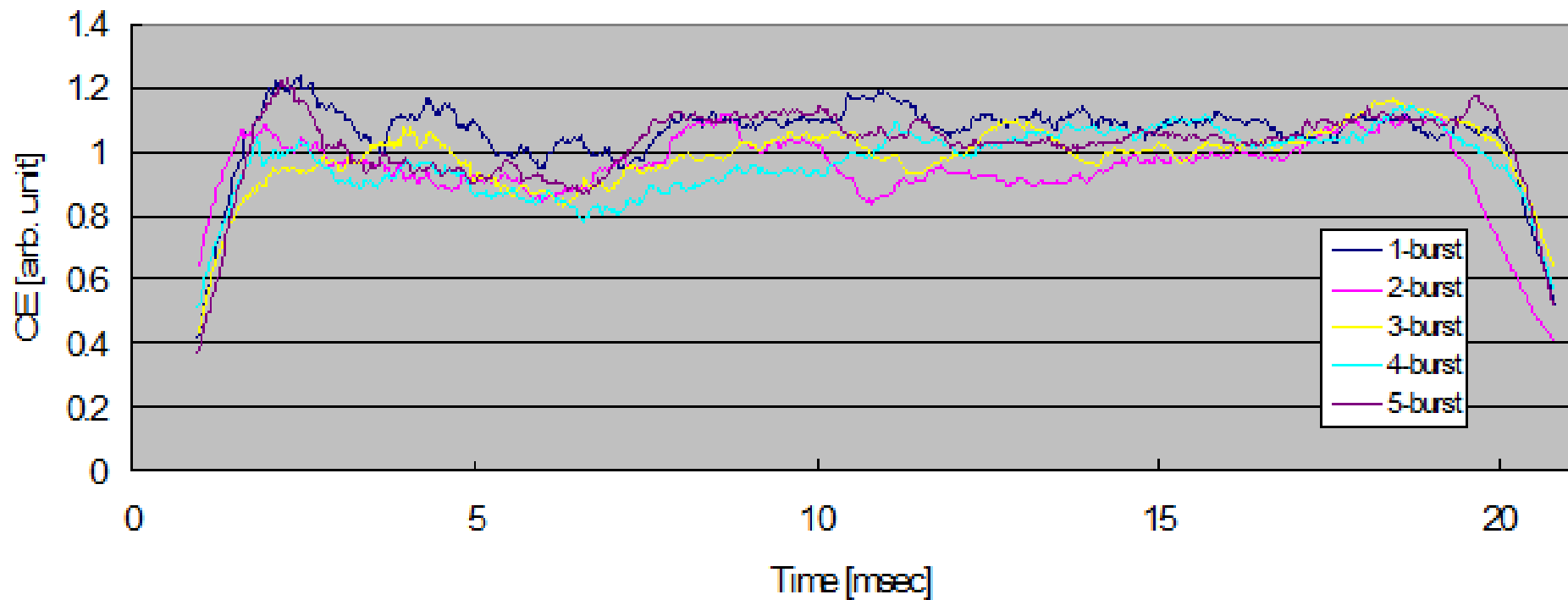


# System operation Data (1)

	<b>Last data (SPIE 2010)</b>	<b>Present</b>
<b>Average power (@I/F)</b>	<b>14 W</b>	<b>21 W</b>
<b>Brightness (@I/F)</b>	<b>69 W</b>	<b>104 W</b>
<b>Duty cycle</b>	<b>20 %</b>	<b>20 %</b>
<b>Max. non stop op. time</b>	<b>&gt;1 hr</b>	<b>&gt;1 hr</b>
<b>Average CE</b>	<b>2.3 %</b>	<b>2.5 %</b>
<b>Dose stability (simulation)</b>	<b>(+/- 0.15%)</b>	<b>(+/- 0.15%)</b>
<b>Droplet diameter</b>	<b>60μm</b>	<b>60μm</b>
<b>CO<sub>2</sub> laser power</b>	<b>5.6 kW</b>	<b>7.9 kW</b>

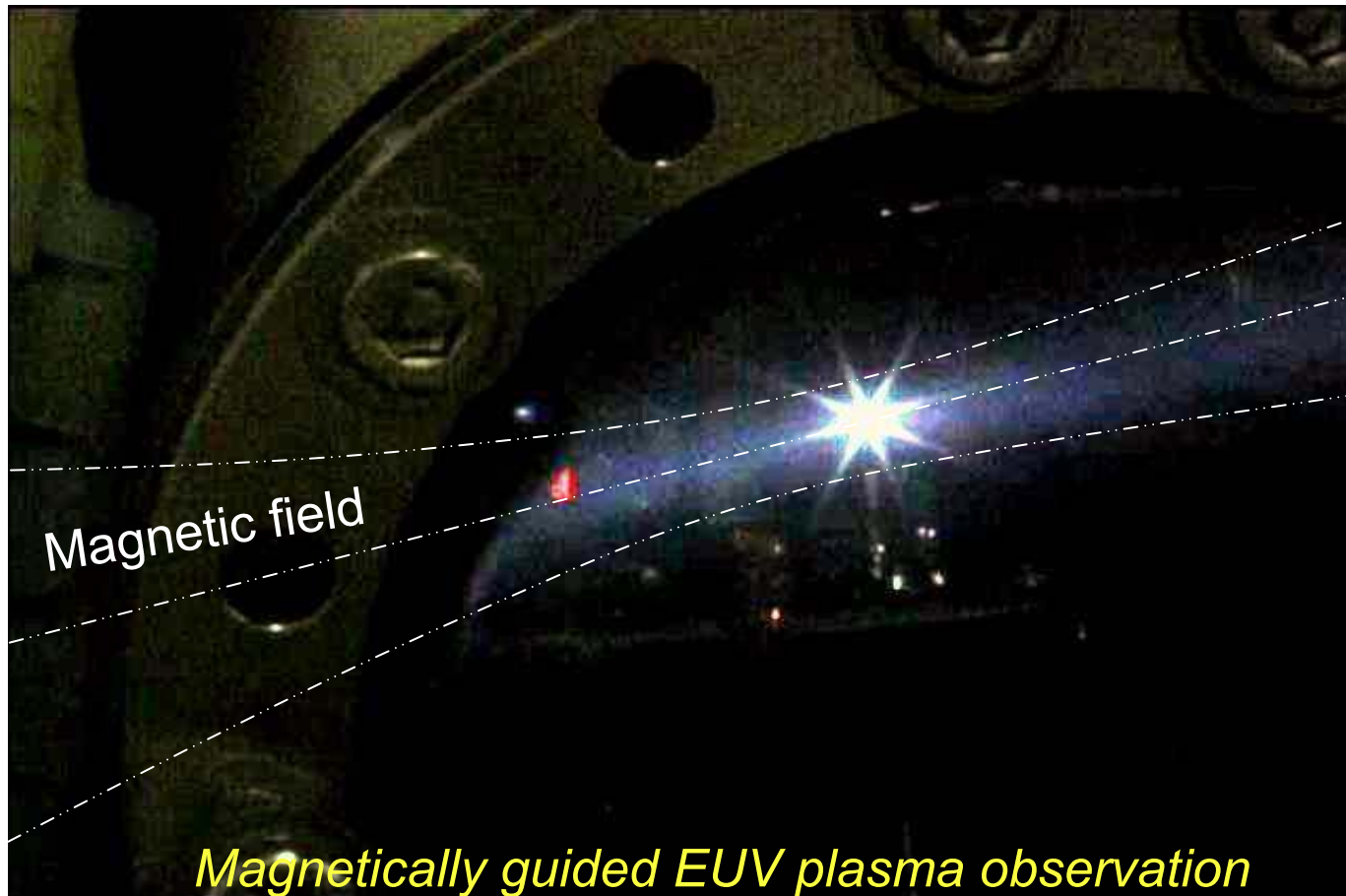
## System operation Data (2)

### ➤ Burst stability data ( 70W open loop )

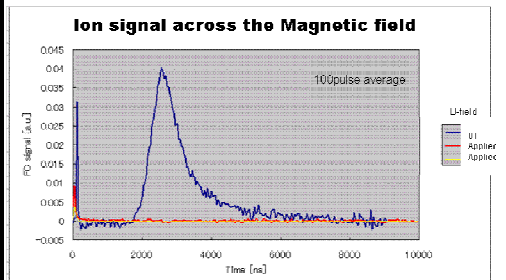
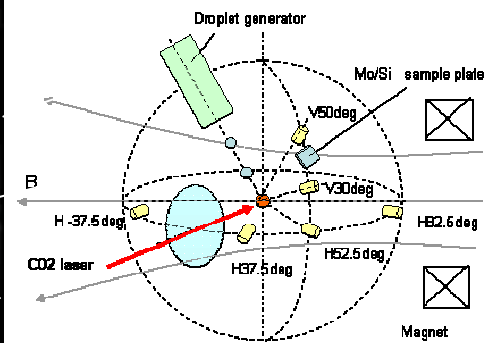


## System operation data (3)

**Fast Ions are perfectly shielded across magnetic field !**



### Ion measurement



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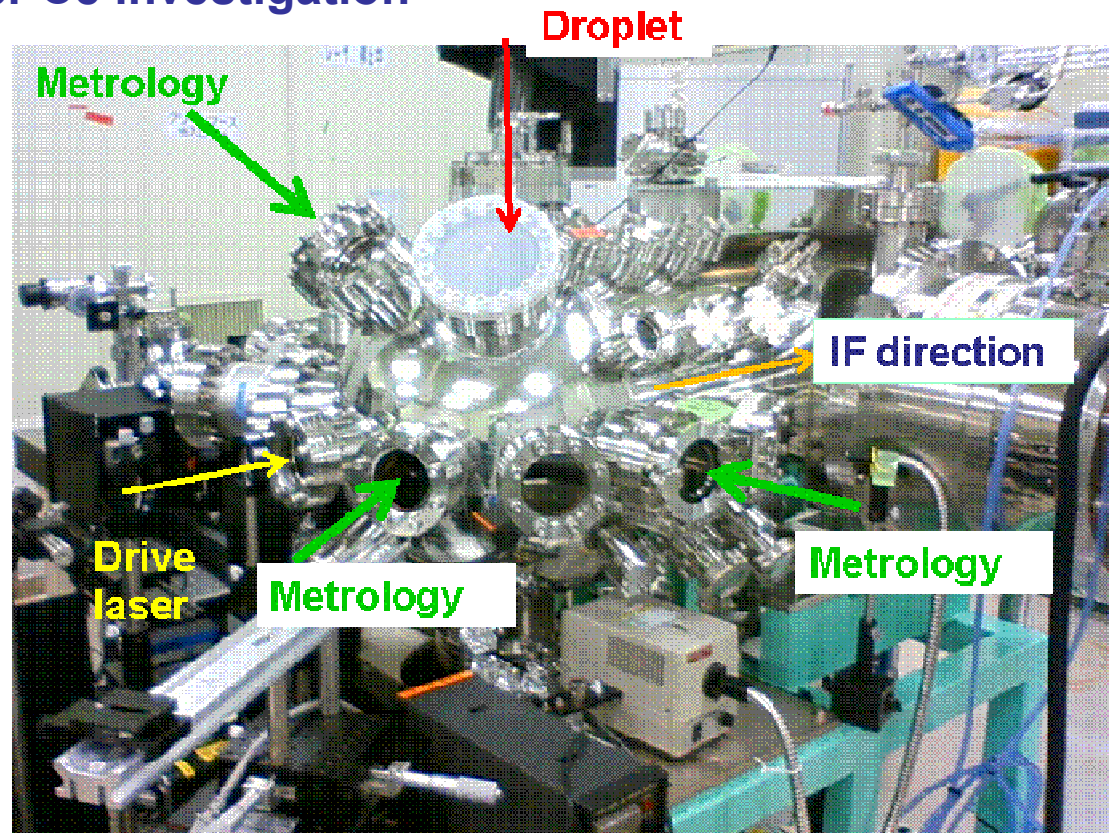
- ✓ Laser power 5kW
- ✓ Duty 20% (ON 200msec:OFF 800msec)

**EUVA**

# Critical issue investigation

(Experiment with research device 10Hz experiment)

- Double pulse optimization
- Debris mitigation mechanism
- Higher Ce investigation



# Liquid droplet experiment

Shadowgraphs of the liquid droplet target

Nd:YAG Laser

Wavelength : 1064 nm

Pulse length : 5 ns (FWHM)

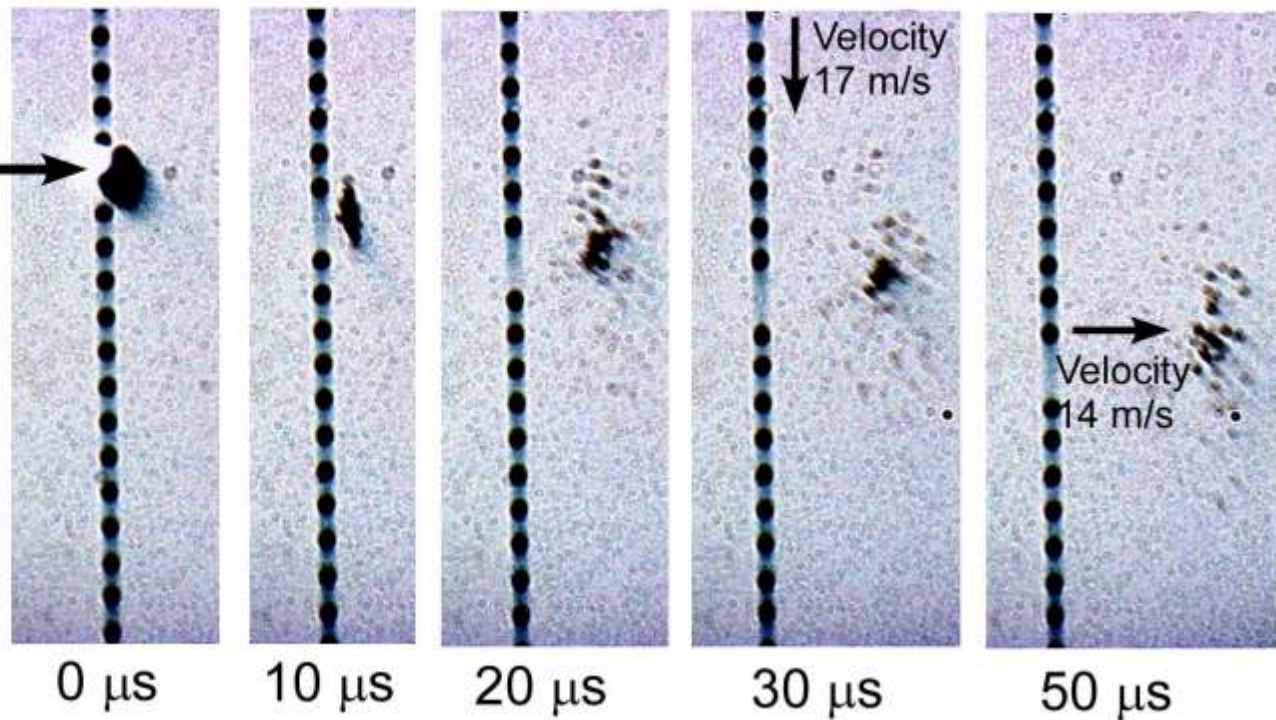
Spot size :  $\sim \Phi 100 \mu\text{m}$

Laser intensity

:  $\sim 1.6 \times 10^9 \text{ W/cm}^2$

Target

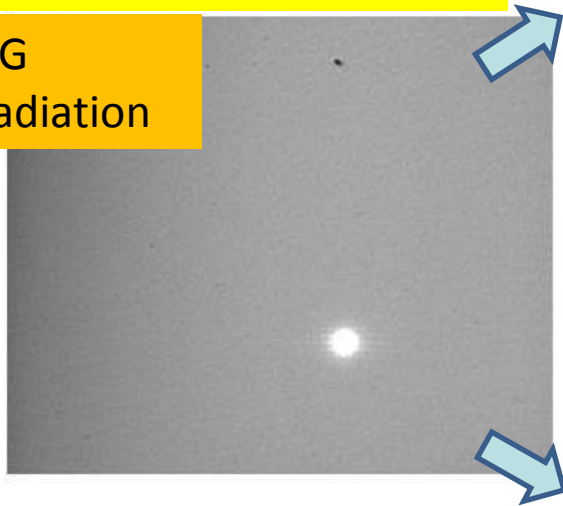
Liquid droplet :  $\Phi 60 \mu\text{m}$



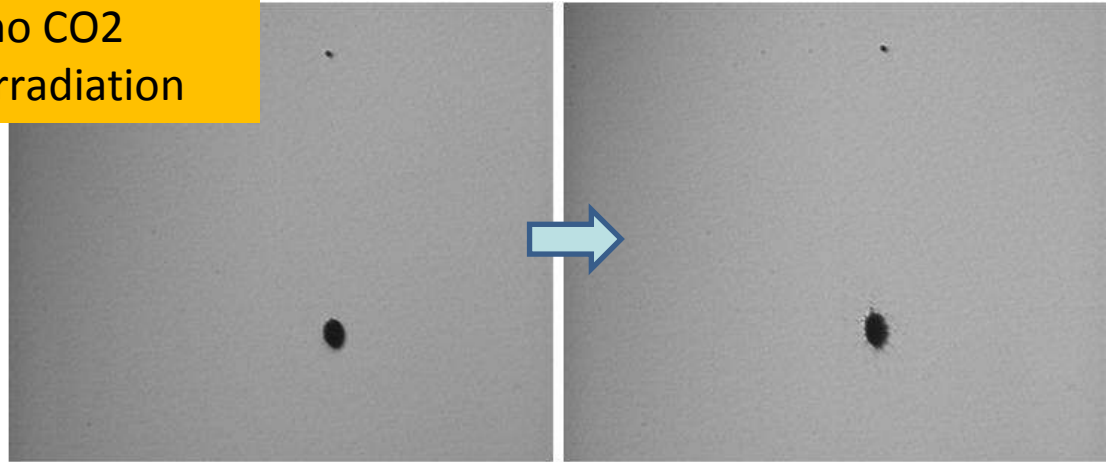
# Liquid droplet experiment with double-pulse

Perfect evaporation and high  $Ce(=2.2\%)$  with double pulse irradiation at around 20 micron Tin droplet is demonstrated.

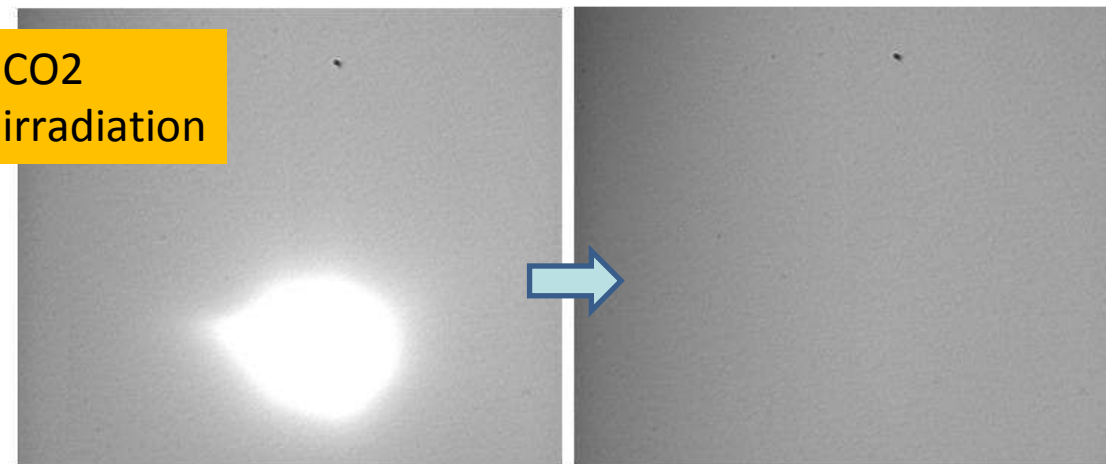
YAG irradiation



no CO2 irradiation



CO2 irradiation



**SO-04** T. Hori "Investigation on high conversion efficiency and tin debris mitigation for LPP EUV light source."

**SO-P15** A. Sunahara "Radiation Hydrodynamic Simulation of laser produced Tin plasma."



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# EUV Light Source Major Specifications

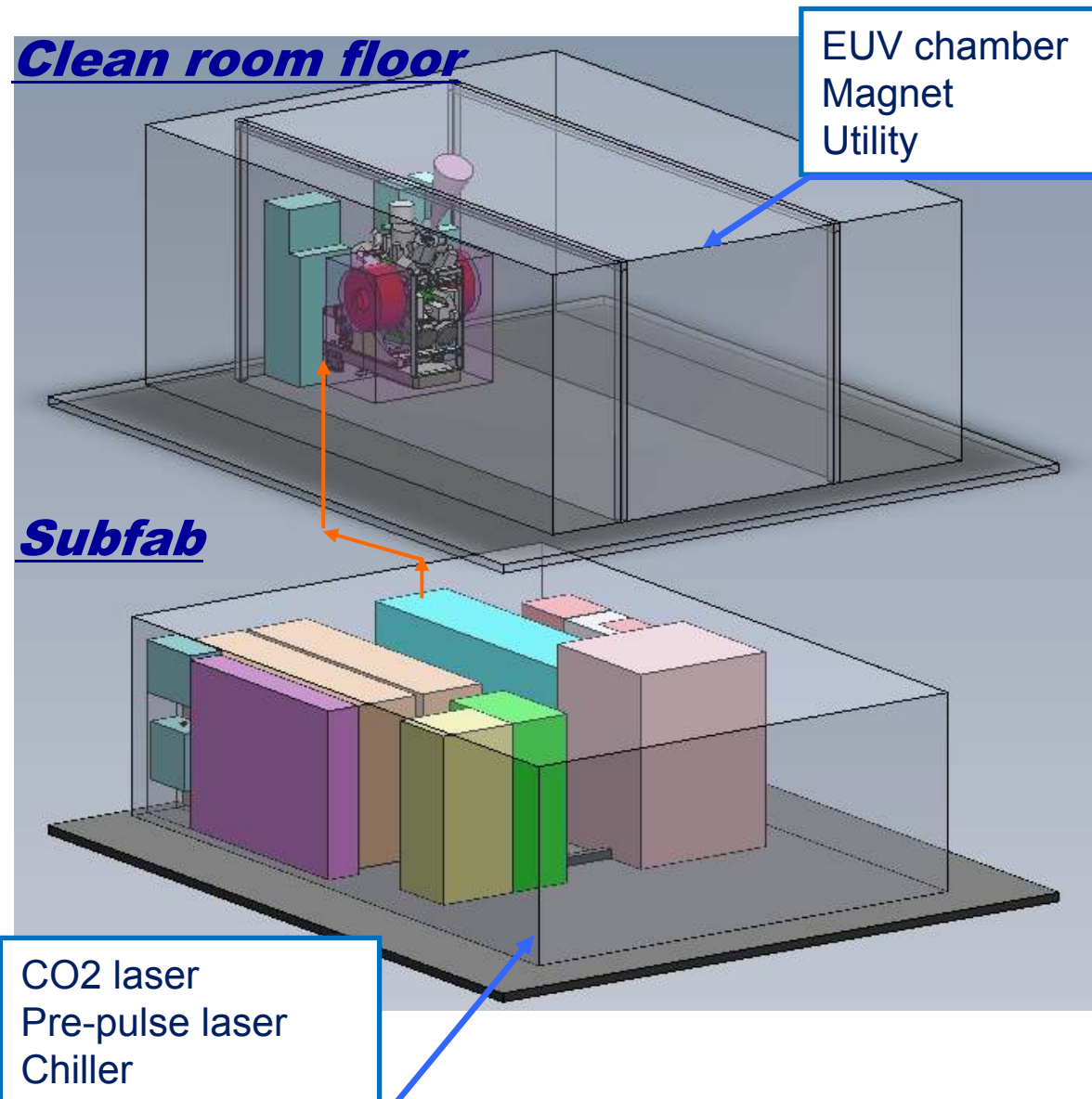
*2<sup>nd</sup> generation GL-200E-proto is under development !*

*1<sup>st</sup> generation*

*2<sup>nd</sup> generation*

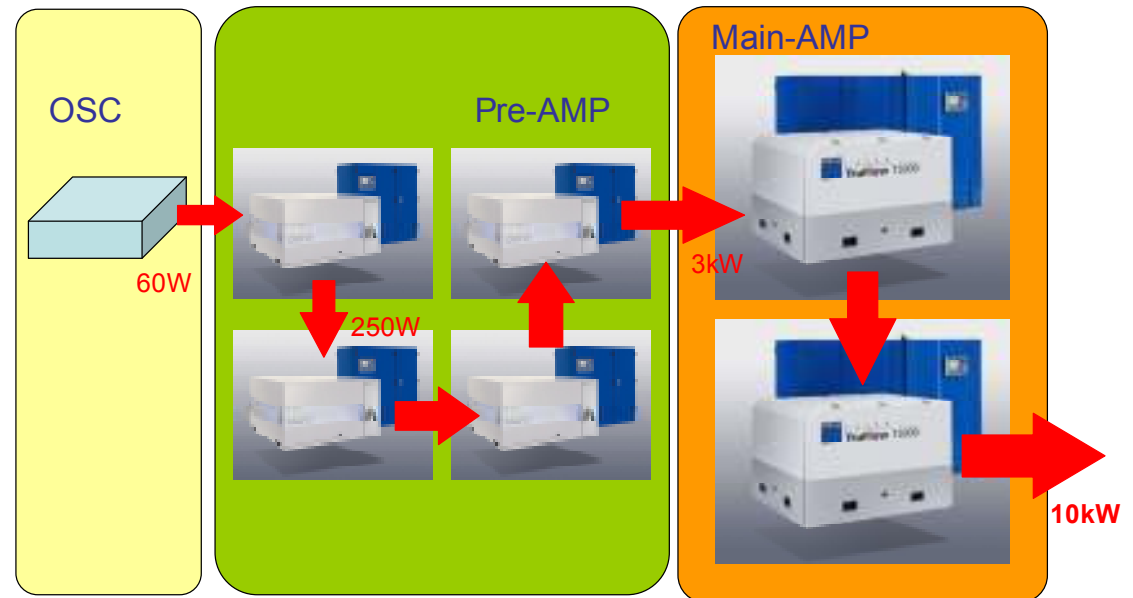
EUV model		ETS	GL200E proto	GL200E
Power	W	100	>100	>250
Pulse energy	mJ	1	>1	>2.5
Max rep rate	kHz	100	100	100
Max Duty Cycle	%	75	>75	>75
Sub systems				
Target Material and Shape		Sn droplet	Sn droplet	Sn droplet
Droplet Diameter	micro meter	60	10	10
Debris Mitigation		Magnet and cleaning	Magnet and cleaning	Magnet and cleaning
Collector Mirror Lifetime	Bpls	11	>200	>1250
Tool Interface		No	Yes	Yes

# GL200E-proto System Overview



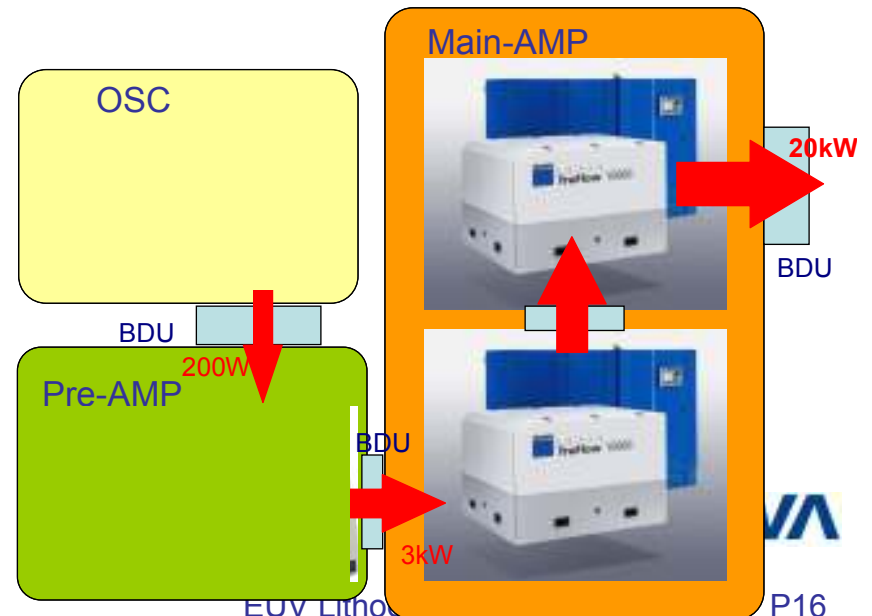
## 2<sup>nd</sup> gen. high power pulsed CO2 laser system

### ● 1<sup>st</sup> gen. laser system



### ● 2<sup>nd</sup> gen. laser system

- Compact: footprint -> <50%
- Efficient: Plug in eff. x2
- Higher power: 10kW-> 20kW



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## 2<sup>nd</sup> Gen. CO<sub>2</sub> laser system is under construction



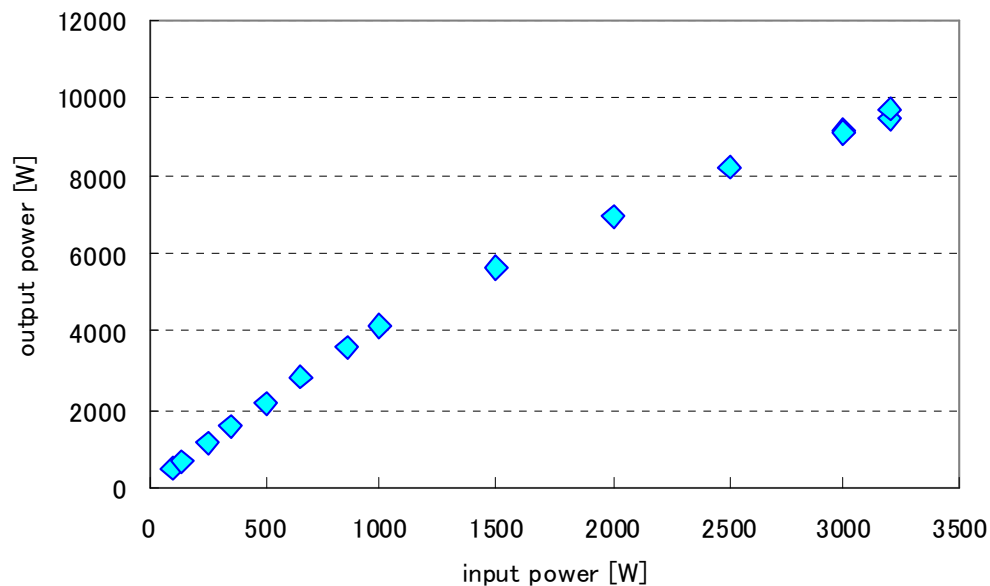
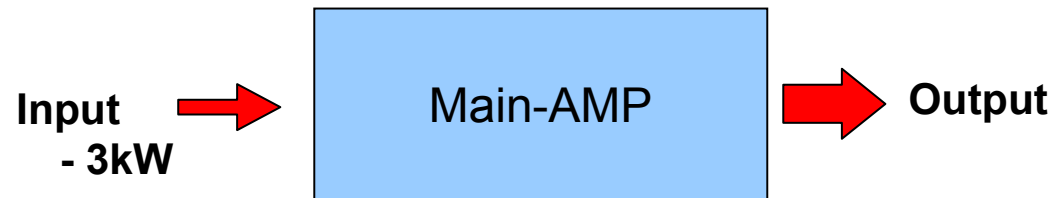
**KOMATSU**

**EUVA**

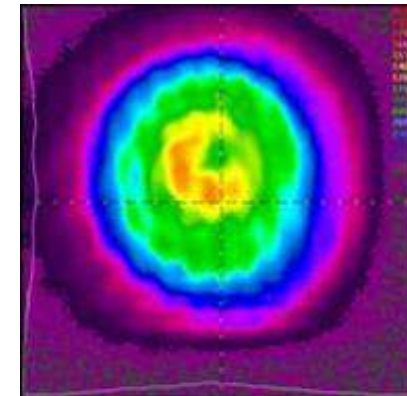
# Main Amplifier performance

## ➤ Main amplifier characteristics : experimental results

- ✓ ~10kW output achieved at 3kW input power
- ✓ Good beam quality:  $M^2 < 2.0$



Output beam profile



## 2<sup>nd</sup> Gen. Magnet system is under construction

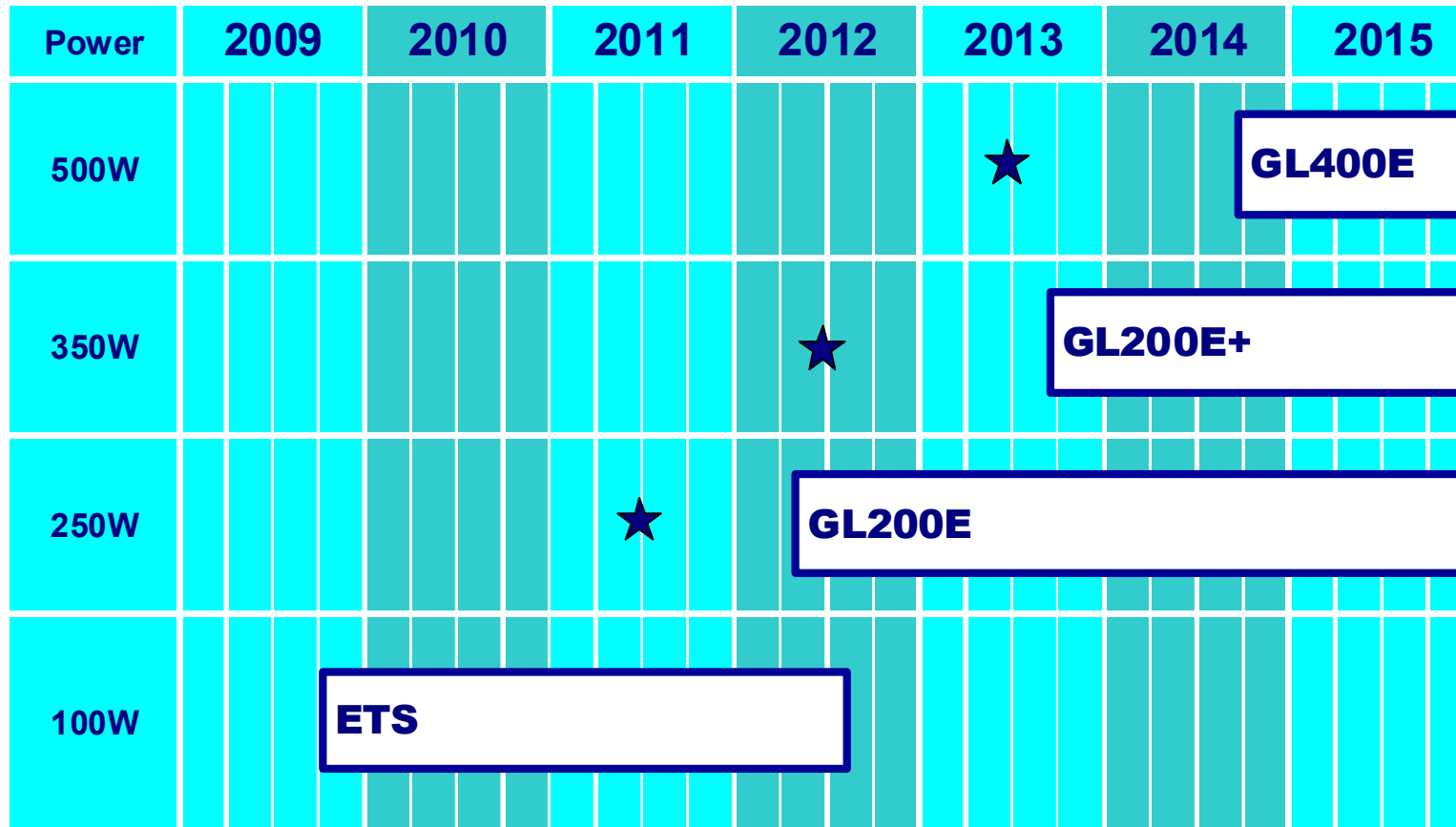




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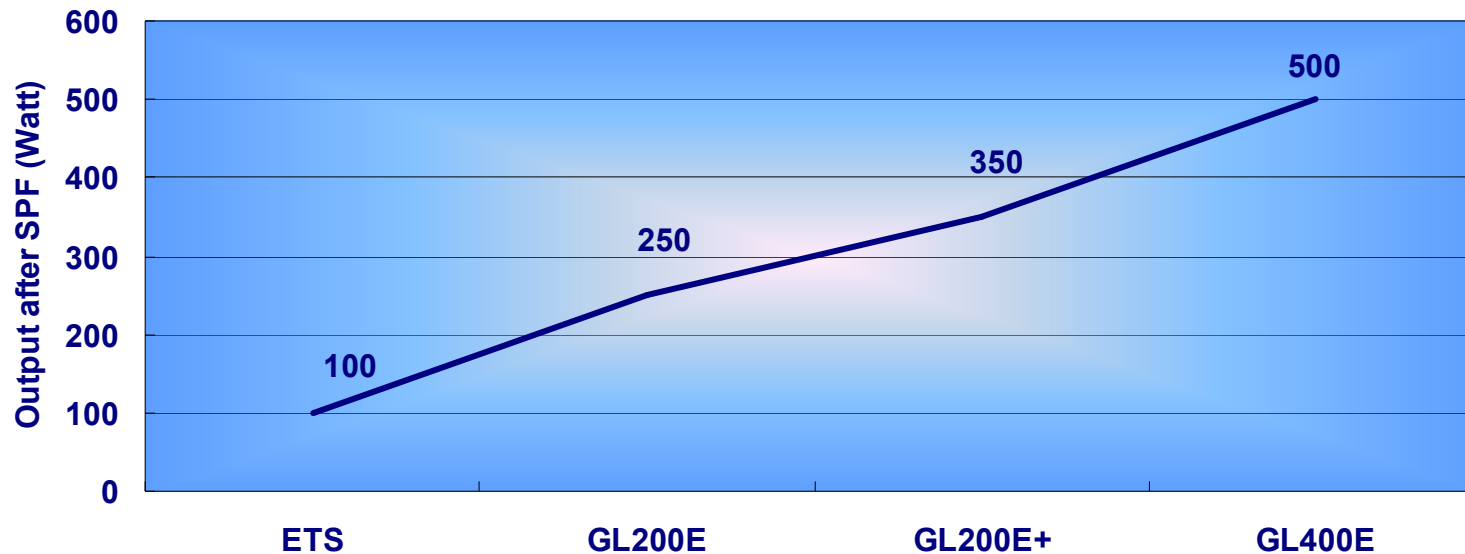
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# Gigaphoton EUV roadmap



★ 1st source delivery

# Power roadmap (Clean EUV Power)



EUV model		ETS	GL200E	GL200E+	GL400E
Drive laser power	kW	10	23	33	40
Conversion efficiency	%	3.0	5.0	5.0	6.0
C1 mirror collector angle	sr	5.5	5.5	5.5	5.5
efficiency*	%	74	74	74	74
C1 mirror reflectivity	%	(50)	57	57	57
Optical transmission	%	95	95	95	95
SPF (IR, DUV)	%	N/A**	62	62	62
Total EUV power (after SF	W	100	250	350	500

# LPP-EUV Development Facility (1)

- ✓ Shinomiya, Hiratsuka (60km south-west from Tokyo)
- ✓ In industry park of Hiratsuka beside the Sagami river
- ✓ Production capacity is up to 4 units/year (at present)
- ✓ Building is extendable to surrounded open space



## LPP-EUV Development Facility (2)





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# Summary

## ■ ETS-2 (1<sup>st</sup> generation integrated setup LPP source)

- Latest operation data is reported
  - 104W at duty cycle of 20% (i.e. average power = 21W)
  - Stability under burst operation  $< \pm 0.23\%$  (dose simulation)
  - Long term ( > 1 hour operation)
- Investigation of critical issue is in advance at research device.
  - Under 20 micron Tin droplet can evaporate perfectly with double pulse method.

## ■ 2<sup>nd</sup> generation LPP source

- Construction of 1<sup>st</sup> proto machine is on going.
  - CO<sub>2</sub> laser operate with good beam quality around 10kW 30% duty.
  - Super conductive magnet is installed.

## ■ Product roadmap and new facility

- Target specification and schedule of Gigaphoton LPP source product is updated.
- New EUV facility is introduced.

# Acknowledgments

## ■ ***Thanks to funding***

This work was partly supported by the New Energy and Industrial Technology Development Organization -NEDO- Japan.

## ■ ***Thanks to co-workers***

- Tamotsu Abe, Yukio Watanabe, Takanobu Ishihara, Takeshi Ohta, Tsukasa Hori, Akihiko Kurosu, Hiroshi Komori, Kouji Kakizaki, Akira Sumitani

*EUVA/Komatsu (Japan): 1200 Manda, Hiratsuka, Kanagawa, 254-8567, Japan*

- Osamu Wakabayashi, Hiroaki Nakarai, Junichi Fujimoto

*Gigaphoton (Japan): 400 Yokokura shinden, Oyama, Tochigi, 323-8558 Japan*

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